Semi-Annual Technical Report
1 May 1976 to 30 September 1976

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Research in Seismology

Semi-Annual Technical Report

Contract F44620-73-C-0042

Table of Contents

Technical Report Summary

Determinations of mean Rayleigh and Love wave attenuation coefficients for Eurasia, as well as regionalized Rayleigh wave attenuation coefficient values, have been presented in the previous semi-annual technical report. New results related to that project include a comparison of fundamental mode Rayleigh wave attenuation coefficients for shield regions of Eurasia with those of eastern North America. The similarity of the results suggests that the shear wave Q distribution beneath those two shield regions is also similar. Higher mode Rayleigh and Love wave attenuation coefficients have been determined for such shield regions, as well as a region which can be classified as tectonic. These values should be useful for theoretical seismogram computations which include the effect of anelastic properties.

Studies of the effects which low-velocity, low-Q sediments have on Rayleigh wave amplitudes have continued. The variation of spectral amplitudes with distance and frequency has been computed for various two-layer velocity and Q models. Observations in the Mississippi embayment suggest that Rayleigh wave amplitudes at short periods can be used to estimate shear wave Q values or thicknesses of low-Q sediments in that region.

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Introduction

This project is concerned with the study of amplitudes of seismic waves, particularly for paths across the Eurasian continent. Topics within this framework include studies of the properties of sources within continental regions and near plate boundaries, and also with the attenuation properties of surface waves across stable and tectonic regions.

Work in all of these specific areas has been completed or is nearing completion. New but related studies will be the topics of future technical reports.

The present report will present some new results of surface wave attenuation studies in Eurasia which were not presented in the previous technical report, and will extend studies of the effects of low-velocity, low-Q sediments on Rayleigh wave amplitudes.

Work Completed During the Report Period.

Work accomplished during the six-month period includes the following and is reported in the following pages:

> B. J. Mitchell and N. Yacoub, Studies of Surface
> Wave Attenuation across Eurasia.

> B. J. Mitchell, The Effect of Low-Velocity, Low-Q
> Sediments on Amplitudes of Short Period Ray-
> leigh Waves.

Some of the work on the first item forms part of a Ph.D. dissertation by N. Yacoub. The results of research on this topic reported in the previous technical report and the additional work reported here are included in two manuscripts which have been submitted for publication.

> N. Yacoub and B. J. Mitchell, Attenuation of Ray-
> leigh Wave Amplitudes across Eurasia, submitted
> to Bull. Seism. Soc. Am.

> B. J. Mitchell, N. Yacoub, and A. Correig, A Summary
> of Seismic Surface Wave Attenuation and Its
> Regional Variation Across Continents and Oceans,
> submitted for publication in an American Geophysi-
> cal Union Monograph.

Studies of Surface Wave Attenuation
Across Eurasia.
by N. Yacoub and B. J. Mitchell

Introduction

Most of the work on this topic was presented in the previous semi-annual technical report and will not be repeated here. The most significant result was that Rayleigh wave attenuation at short periods was lower for stable regions of Eurasia than for unstable regions, and that failure to consider regional differences could lead to mean attenuation coefficient determinations which are substantially higher or lower than the true values. This report will present a comparison of the fundamental Rayleigh mode attenuation coefficients for Eurasia and eastern North America, and will present computational results of higher mode surface wave attenuation coefficients for a shield and a tectonic region.

Comparison of Rayleigh Wave Attenuation
across Shield Regions of Eurasia and
North America.

Figure 1 indicates events and stations used for the attenuation coefficient values previously reported, as well as the boundaries for regions designated as stable and tectonic in character. Mean Rayleigh wave attenuation coefficient values for both regions were presented in the previous technical report. The values for stable regions appear in
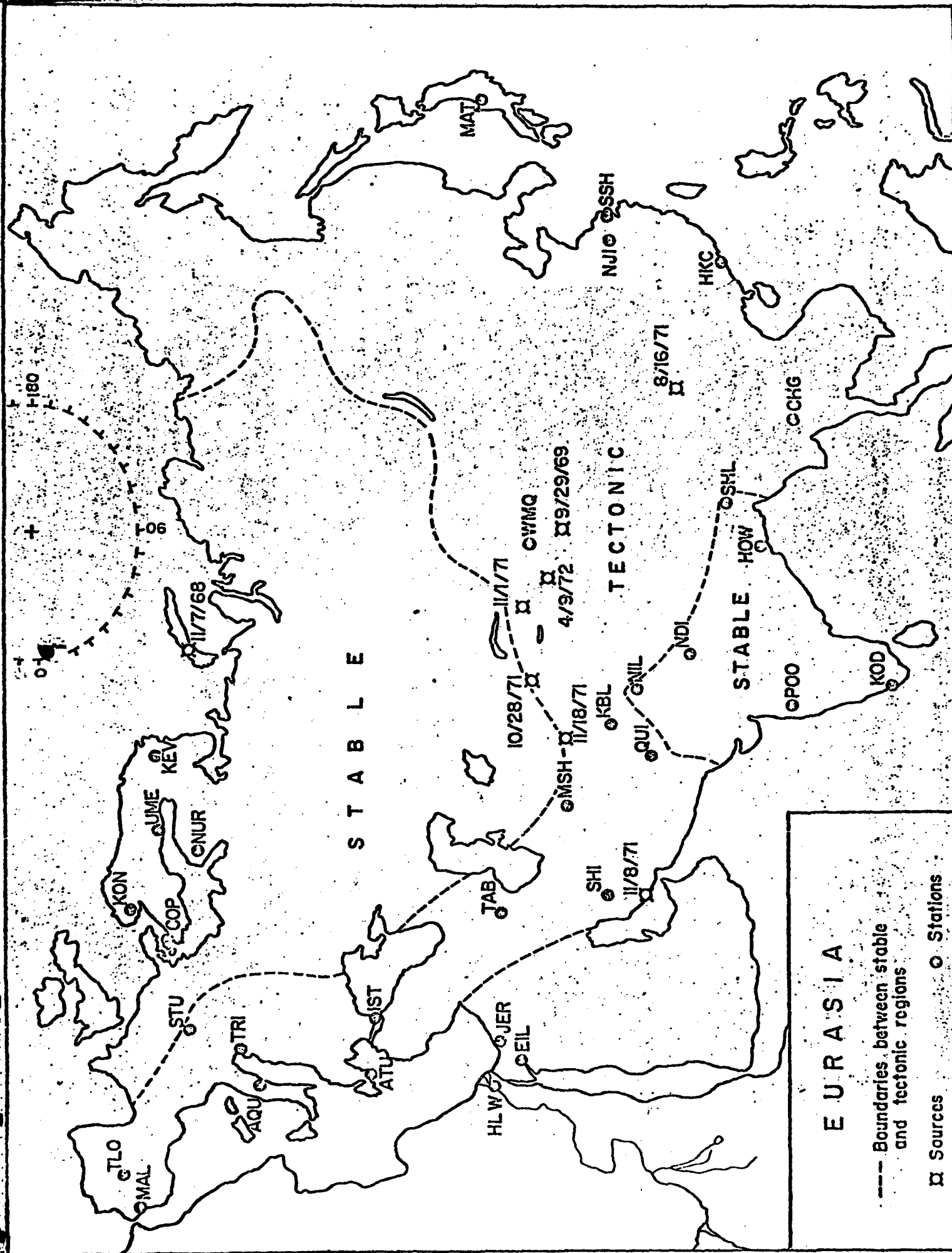
Figure 1. Map of Eurasia indicating the events, stations, and regionalization discussed in the text.

Figure 2 along with those previously determined for eastern North America by Herrmann and Mitchell (1975). It is apparent that the values are quite similar over the entire common period range. The standard deviations for the Eurasian values are larger, and completely span those for North America at most periods. Because of this similarity, it might be expected that the distribution of the shear wave internal friction values (Q_{β}^{-1}) with depth is also similar for the two regions.

<div align="center">Higher Mode Attenuation Coefficients.</div>

The determination of attenuation coefficients for higher mode surface waves is difficult because the modes often either overlap one another or are poorly excited. However, if a velocity and Q model is known for a region, attenuation coefficients for all modes can be computed using the equation

$$\gamma_L = \frac{\pi}{T} \sum_{i=1}^{N} \left(\frac{\beta_i}{C_L^2} \frac{\partial C_L}{\partial \beta_i} \right) Q_{\beta i}^{-1}$$

for Love waves, and

$$\gamma_R = \frac{\pi}{T} \left[\sum_{i=1}^{N} \left(\frac{\alpha_i}{C_R^2} \frac{\partial C_R}{\partial \alpha_i} \right)_{\omega,\beta} Q_{\alpha i}^{-1} + \sum_{i=1}^{N} \left(\frac{\beta_i}{C_R^2} \frac{\partial C_R}{\partial \beta_i} \right)_{\omega,\rho,\alpha} Q_{\beta i}^{-1} \right]$$

for Rayleigh waves (adapted from Anderson et al (1965). In these equations, α is compressional velocity, β is shear velocity, ω is angular frequency, and T is period. C and U are phase and group velocities for the appropriate Love or Rayleigh mode. Subscripts indicate quantities which are held constant.

The model taken to represent stable regions is a combination of the velocity model of McEvilly (1964) and a
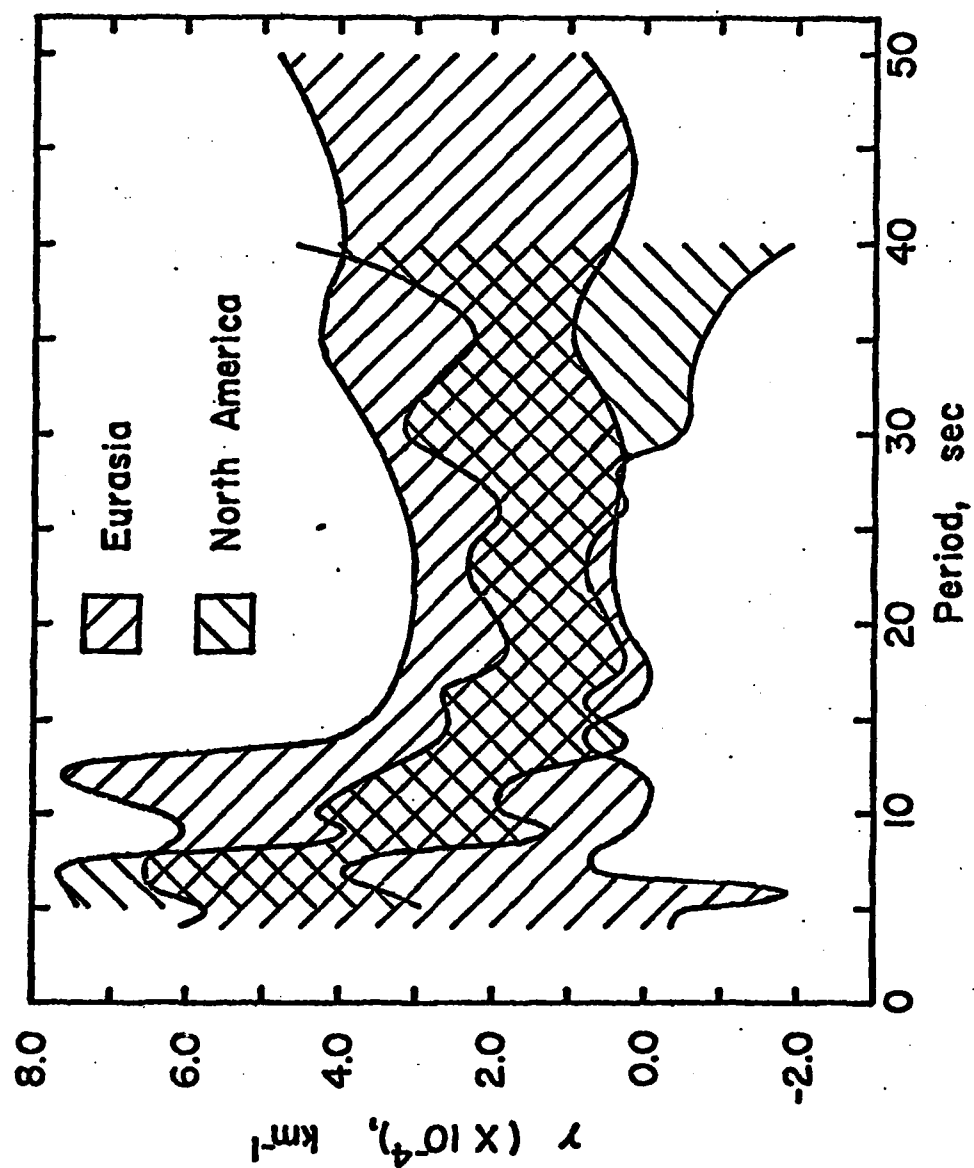
Figure 2. Comparison of attenuation coefficient values for Eurasia with those of eastern North America.
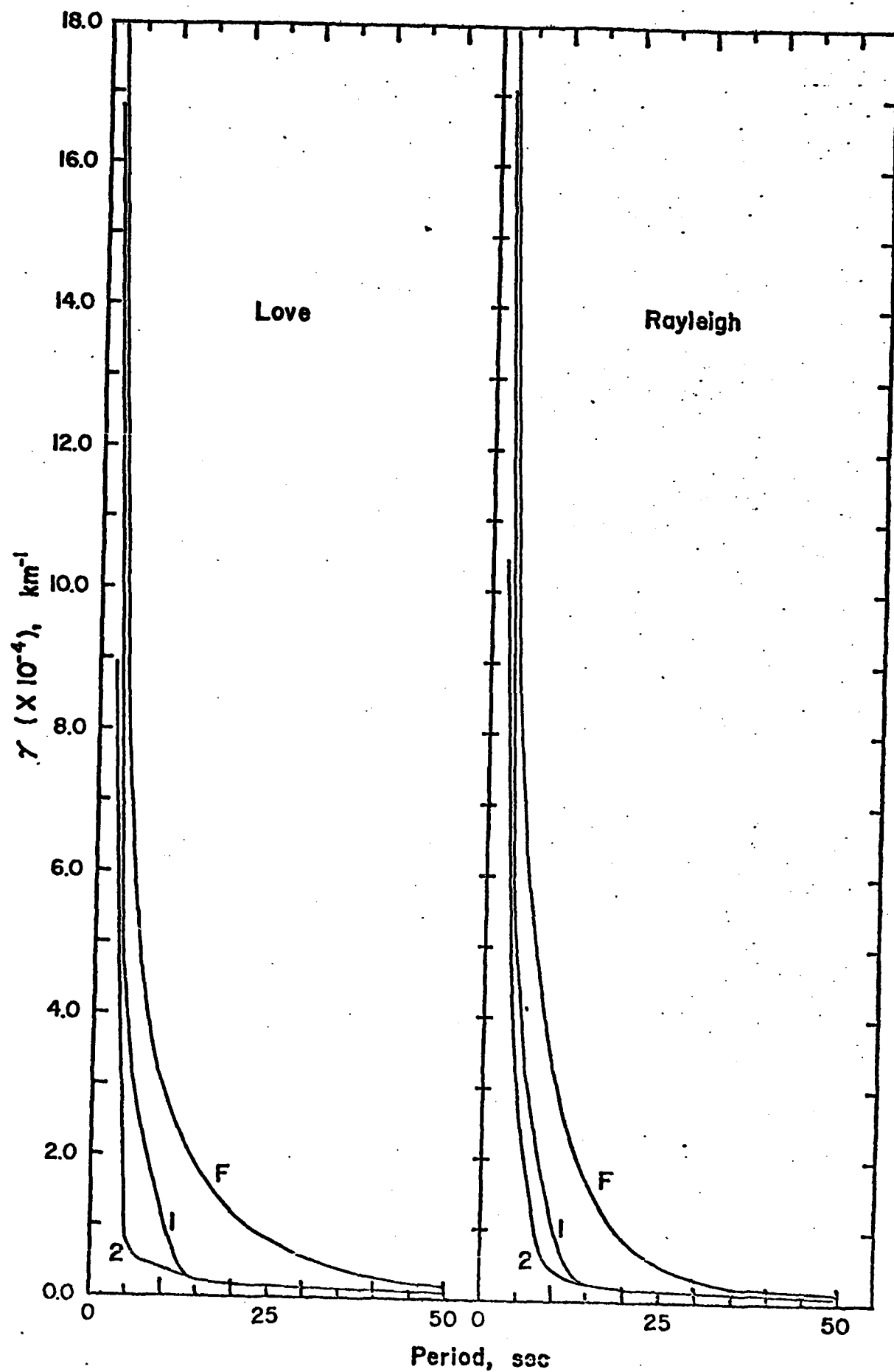
Figure 3. Theoretical attenuation coefficients for the fundamental and 2 higher mode surface waves for a crustal model of eastern North America.
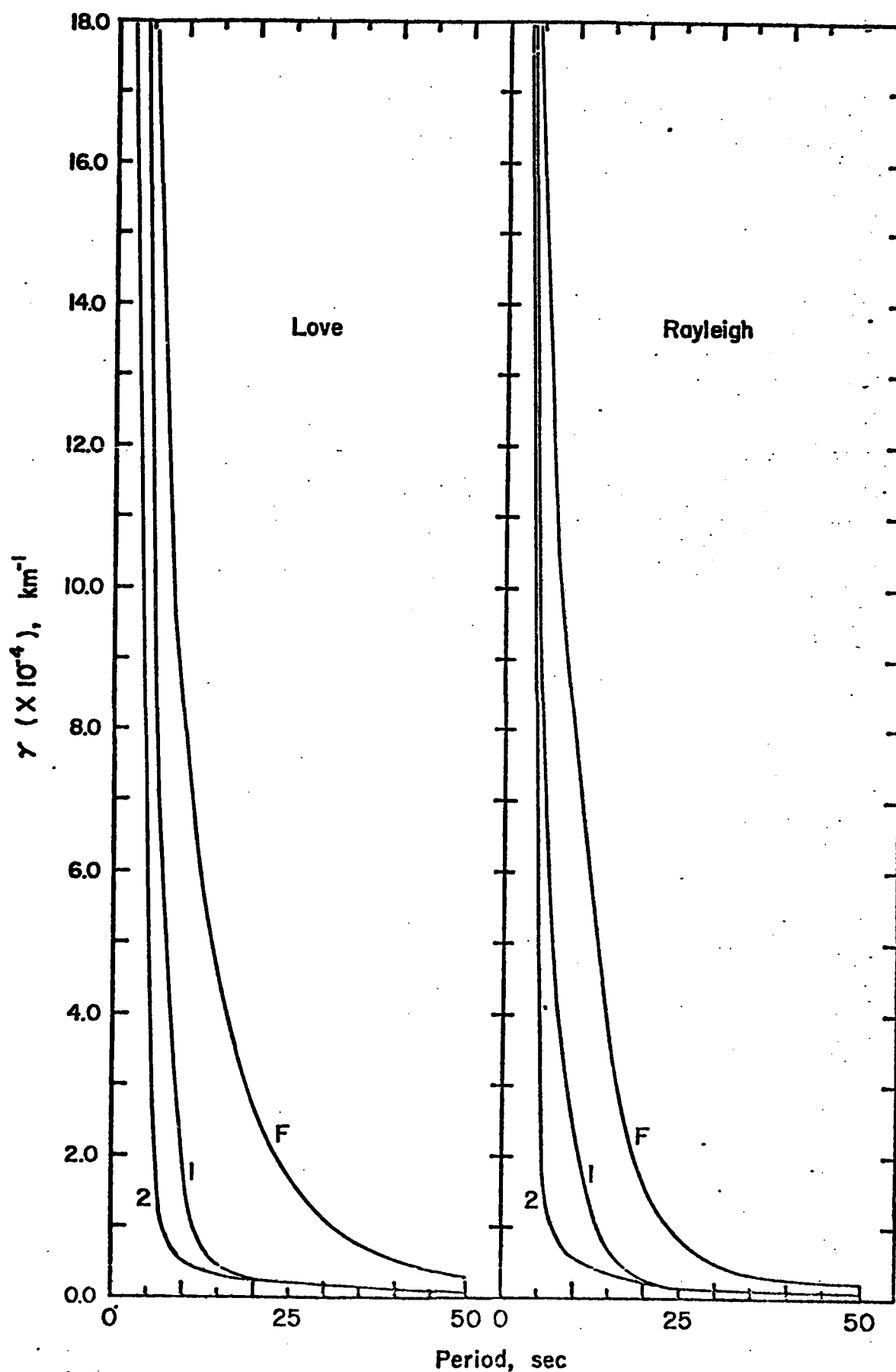
Figure 4. Theoretical attenuation coefficients for the fundamental and 2 higher mode surface waves for a Basin and Range crustal model.

two-layer Q model taken from Herrmann and Mitchell (1975). Results for the fundamental and two higher modes appear in Figure 3 for both Love and Rayleigh waves. The Basin and Range velocity model of Braile et al (1974) and a Q model for western North America from Mitchell (1975) are taken for computations in a tectonic region. The results appear in Figure 4. The attenuation coefficient values for the Basin and Range model are higher for all modes than those of the eastern North America model, especially at short periods. These attenuation coefficient values should be useful for theoretical seismogram computations which include the effect of anelastic attenuation.

References

Anderson, D.L., A. Ben-Menahem, and C. B. Archambeau, Attenuation of seismic energy in the upper mantle, J. Geophys. Res., 70, 1441-1448, 1965.

Braile, L. W., R. B. Smith, G. R. Keller, and R. M. Welch, Crustal structure across the Wasatch front from detailed seismic refraction studies, J. Geophys. Res., 79, 2669-2677, 1974.

Herrmann, R. B., and B. J. Mitchell, Statistical analysis and interpretation of surface wave anelastic attenuation data for the stable interior of North America, Bull. Seism. Soc. Am., 65, 1115-1128, 1975.

McEvilly, T. V., Central U. S. crust-upper mantle structure from Love and Rayleigh-wave phase velocity inversion,

Bull. Seism. Soc. Am., 54, 1997-2015, 1964.

Mitchell, B. J., Regional Rayleigh wave attenuation in North America, J. Geophys. Res., 80, 4904-4916, 1975.

The Effect of Low-Velocity, Low-Q Sediments
on Rayleigh Wave Amplitudes
by B. J. Mitchell

Introduction

The only investigations of the effect of low Q sediments on surface wave amplitudes, to my knowledge, are those which were reported in the previous technical report. In that report Rayleigh wave attenuation coefficients were computed as a function of frequency, and amplitudes were computed as functions of frequency and distance, for various two layer models. The caption for the figure which included attenuation coefficients erroneously indicated that they were plotted as a function of period. This should have read "as a function of frequency" and is corrected in Figure 1 of this report.

Computations of amplitudes as a function of distance at two frequencies appear in Figure 2, and as a function of frequency at two distances appear in Figure 3. Seismic velocities for the computations were taken from Tatham (1975). These results suggest two methods by which Rayleigh wave amplitudes could be used to determine either the Q values or thicknesses of low Q sediments. The first method (Figure 2) requires two or more stations at different distances from the source, whereas the second (Figure 3) requires only one station. The second method also requires that the amplitude spectrum at the source be known. In the calculations which follow, we
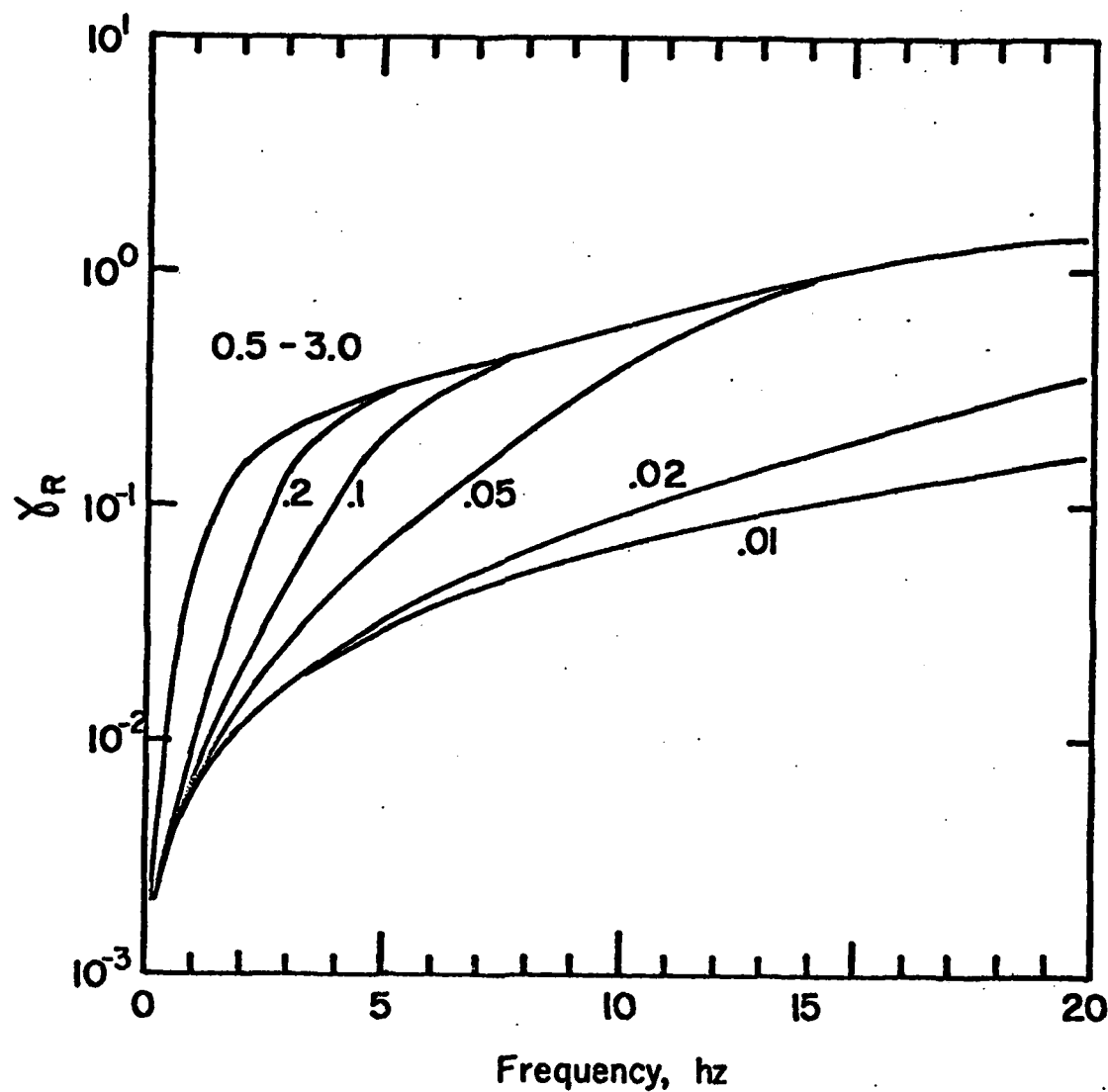
Figure 1. Rayleigh wave attenuation coefficients as a function
of frequency for various thicknesses of low-velocity, low-Q
sediments overlying a higher-velocity, higher-Q half-space.
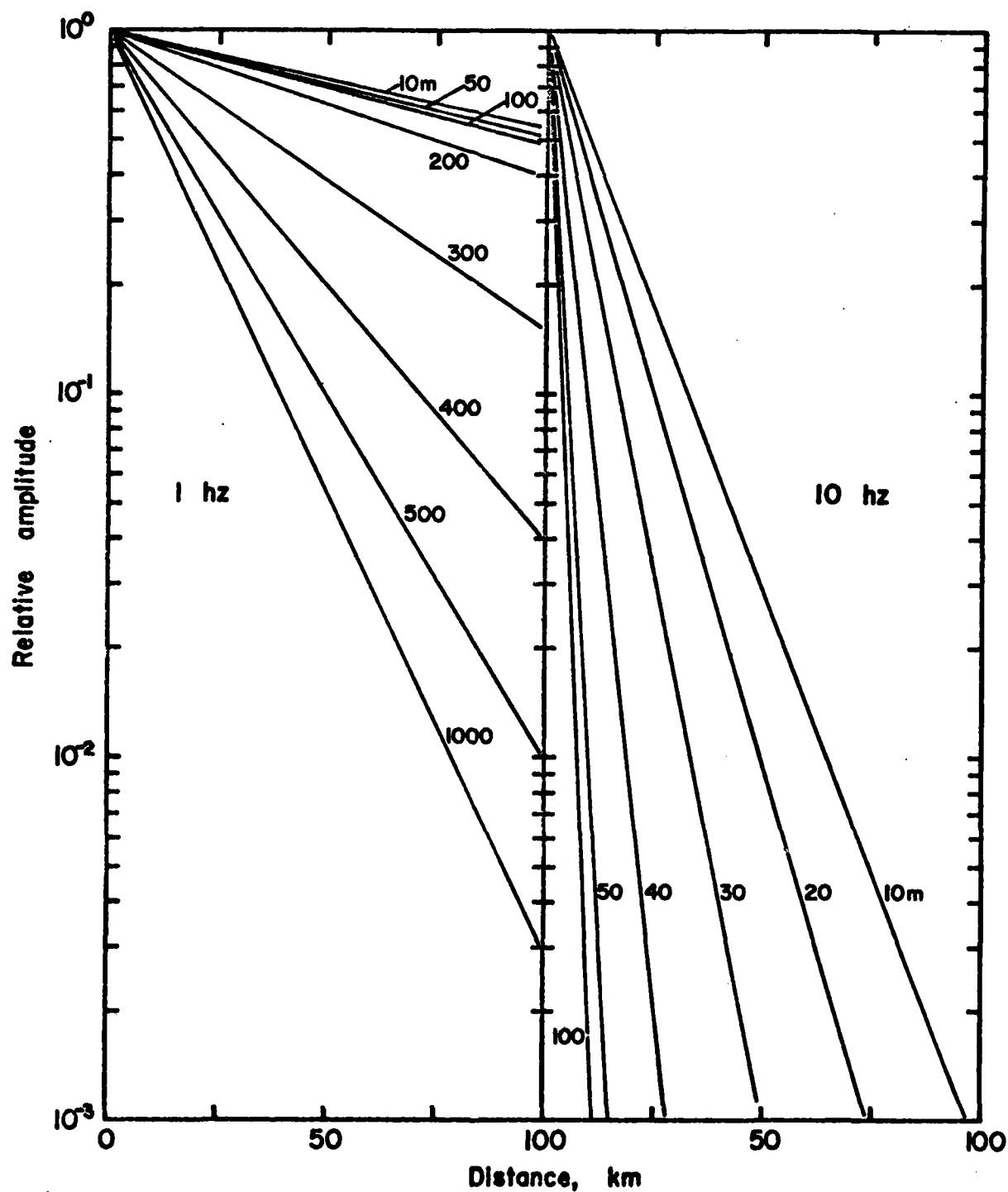The numbers by each curve indicate the layer thicknesses in km.

Figure 2. Relative Rayleigh wave amplitudes at frequencies of
1 hz and 10 hz, as a function of distance, for the attenuation
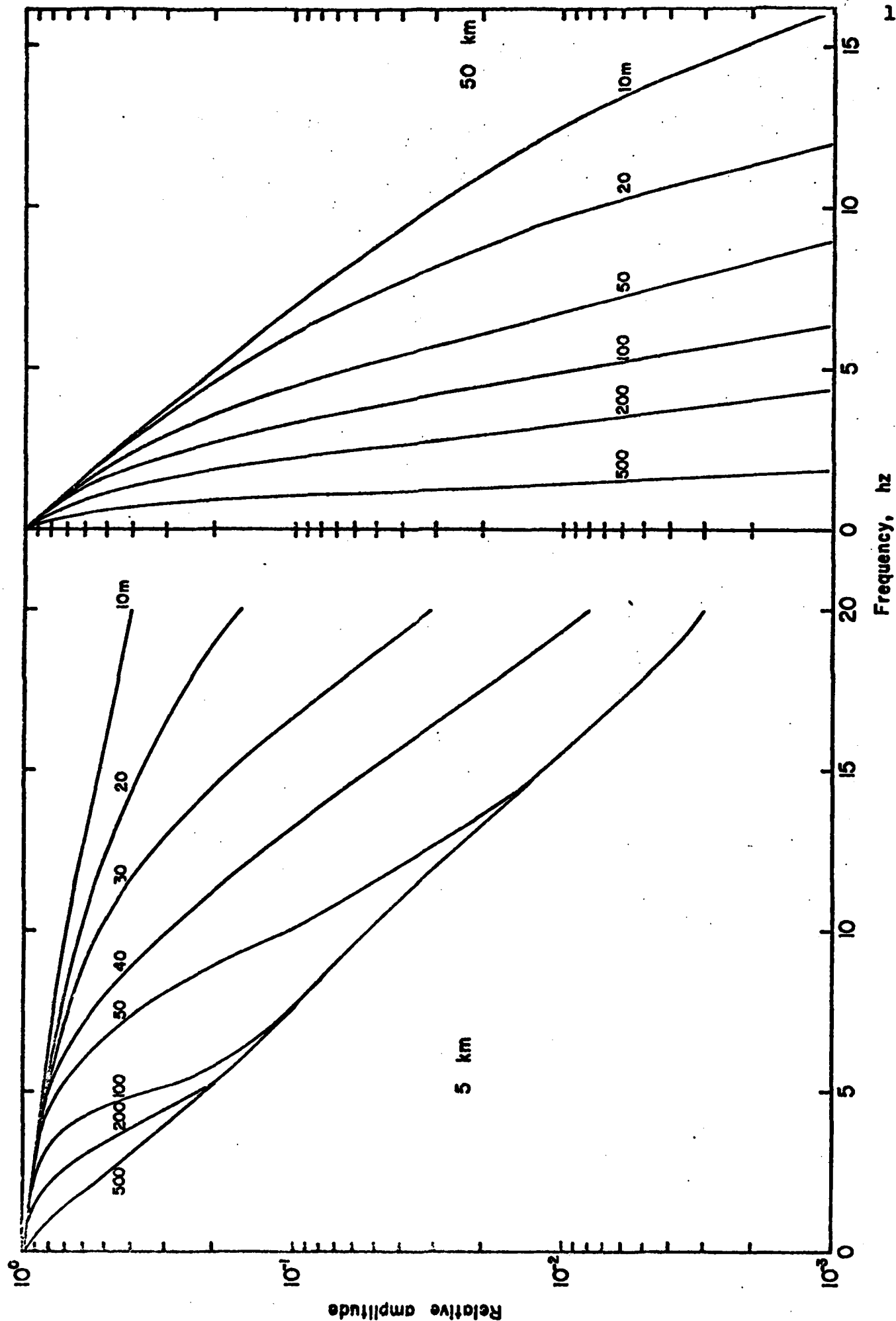coefficients and models indicated by Figure 1.

Figure 3. Relative Rayleigh wave amplitudes at a distance of 5 km and 50 km as a function of frequency, for the attenuation coefficients and models indicated by Figure 1.

16

assume that spectrum to be flat over the frequency range of interest.

The upper Mississippi embayment provides a suitable region in which to test these methods in an alluvial basin. Figure 4 indicates the upper Mississippi embayment and stations of the Saint Louis University regional seismic network. The earthquakes in this region as well as strip mine explosions and quarry blasts just north of the embayment provide suitable sources of Rayleigh waves. One Rayleigh wave recorded at station ELC appears in Figure 5. An unfiltered seismogram appears at the top of the figure, and the same seismogram filtered with various narrow-band filters appear below. These filtered seismograms were used to determine the amplitudes required by the methods depicted by Figures 2 and 3.

Seismograms recorded at ELC for waves generated by quarry blasts in southern Illinois provide an opportunity to test the method for determining Q values. Low-Q glacial deposits in the region are about 20 meters thick, and overlie limestone with much higher Q values. The results of Figure 6 indicate that Q values for the limestone are about 100. The Rayleigh wave amplitudes over the frequency range 1-5 hz are not very sensitive to the Q values of the low-Q material, but are adequately explained by values between about 25 and 50.

Using values of 25 for the low-Q material and 100 for the limestone, an attempt was made to determine the thickness of the low-Q material in a portion of the Mississippi embayment. An earthquake which occurred in the embayment was used
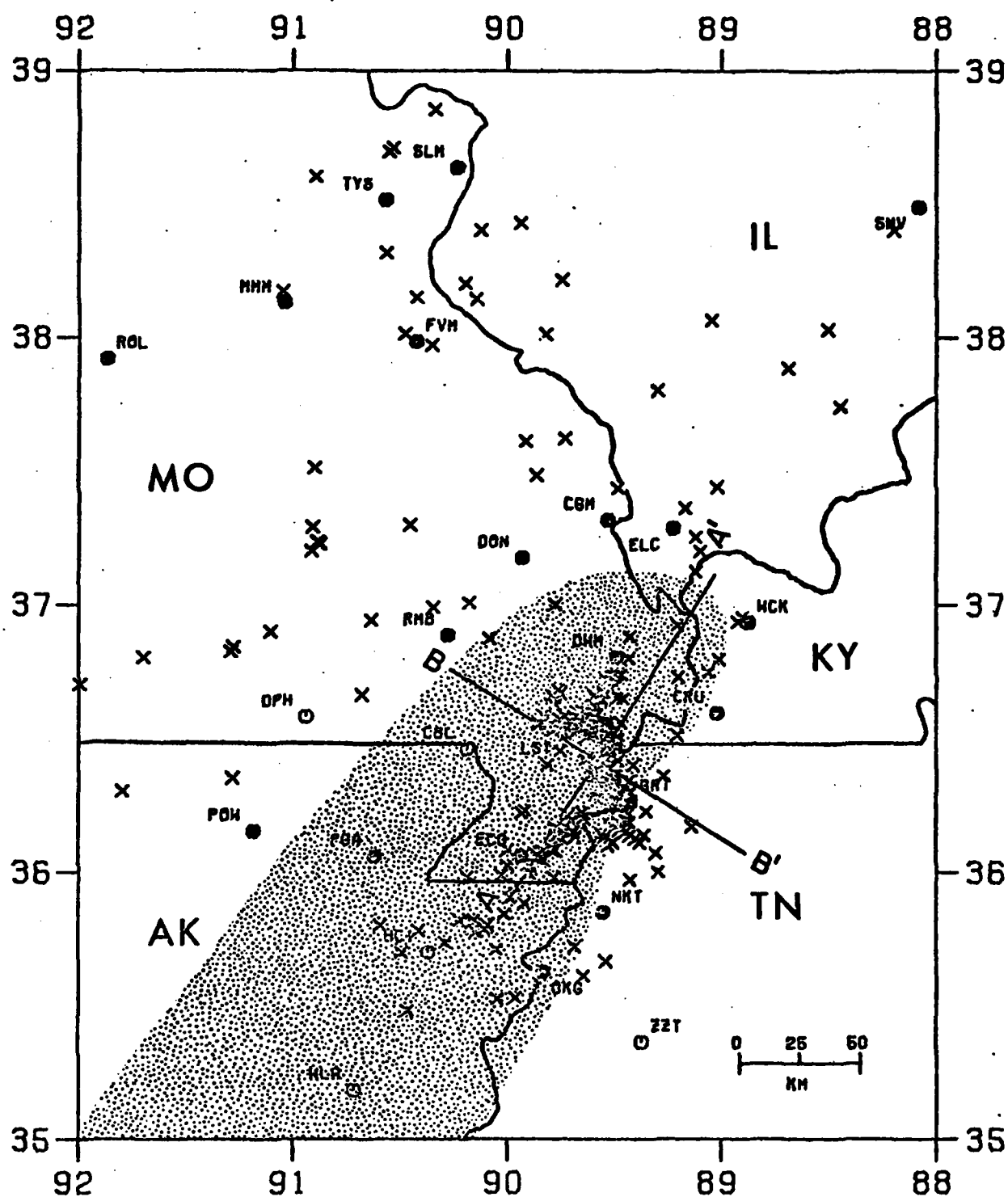
Figure 4. Map of the upper Mississippi embayment (shaded), including
stations of the Saint Louis University network and earthquakes
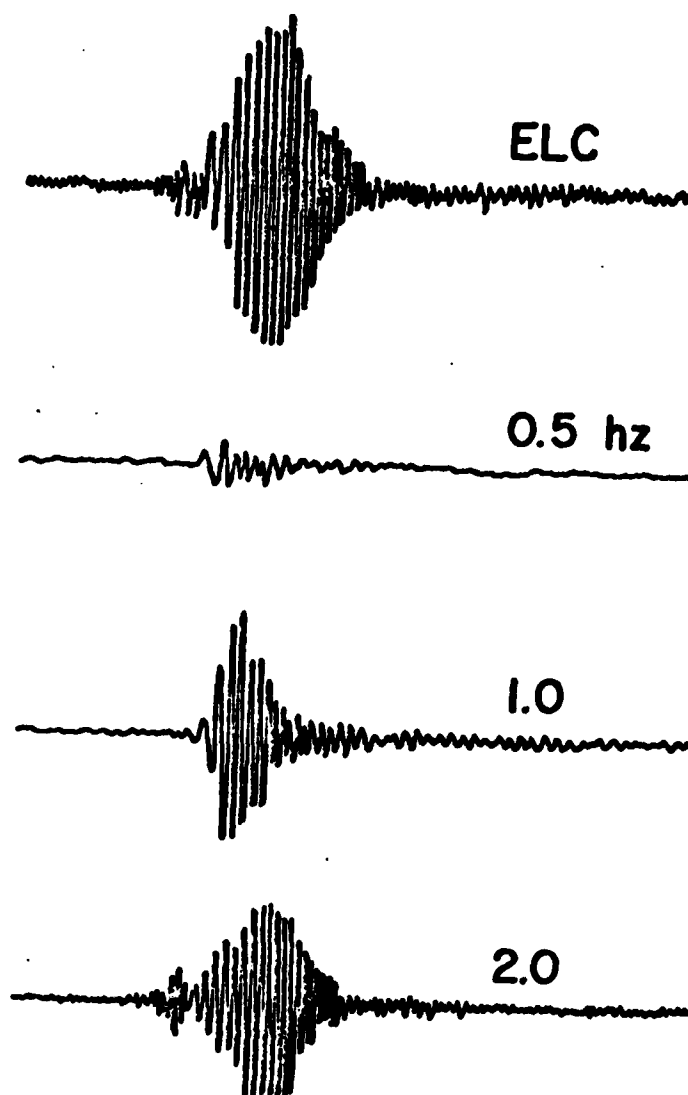which have been located.

Figure 5. Seismogram from a quarry blast recorded at station ELC. The uppermost seismogram is unfiltered and the lower seismograms are filtered by narrow-band filters centered at the indicated frequencies.
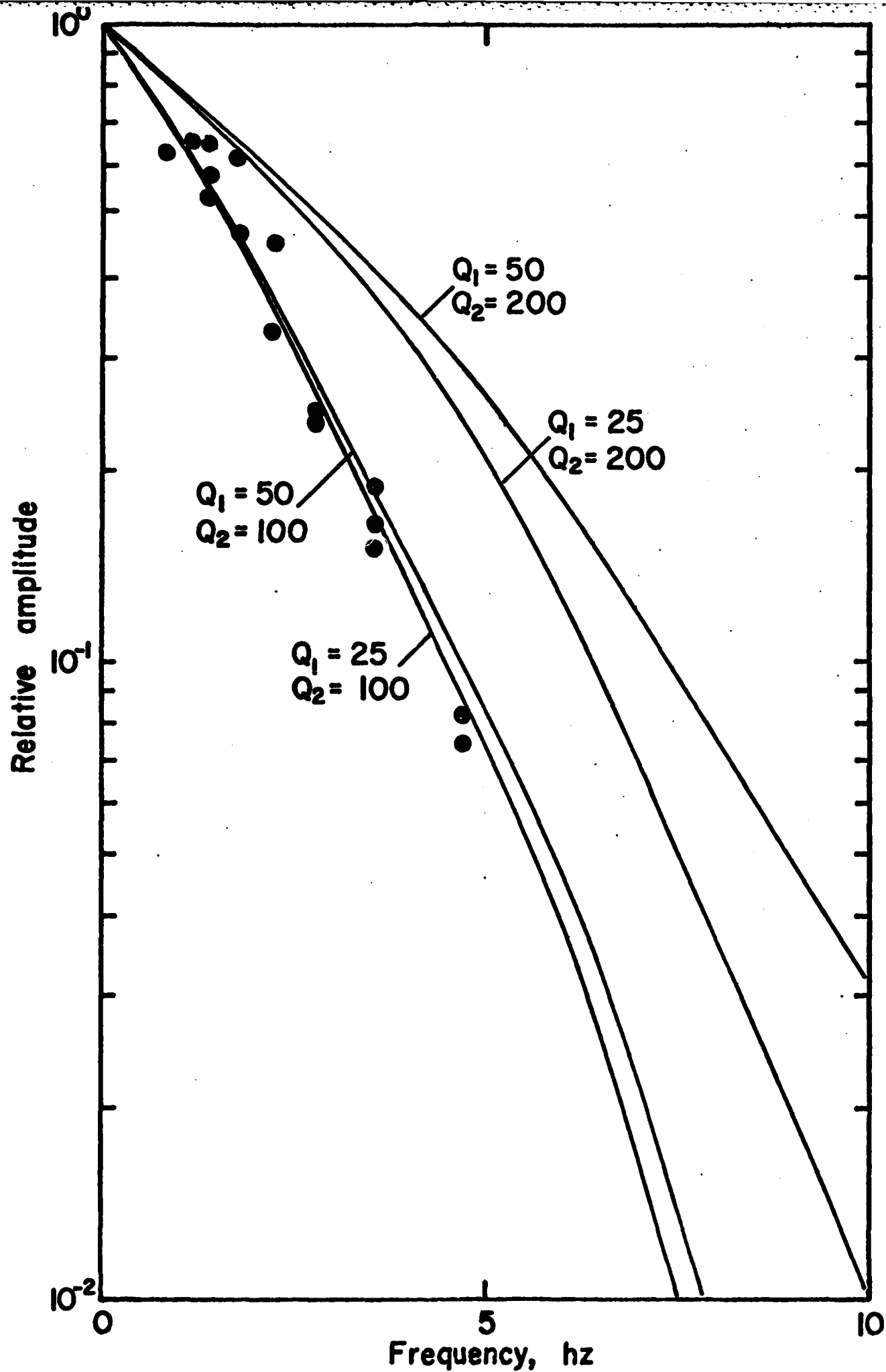
Figure 6. Comparison of observed amplitudes with theoretical amplitudes for various two-layer Q models. The thickness of the low-Q material is taken as 20 meters.
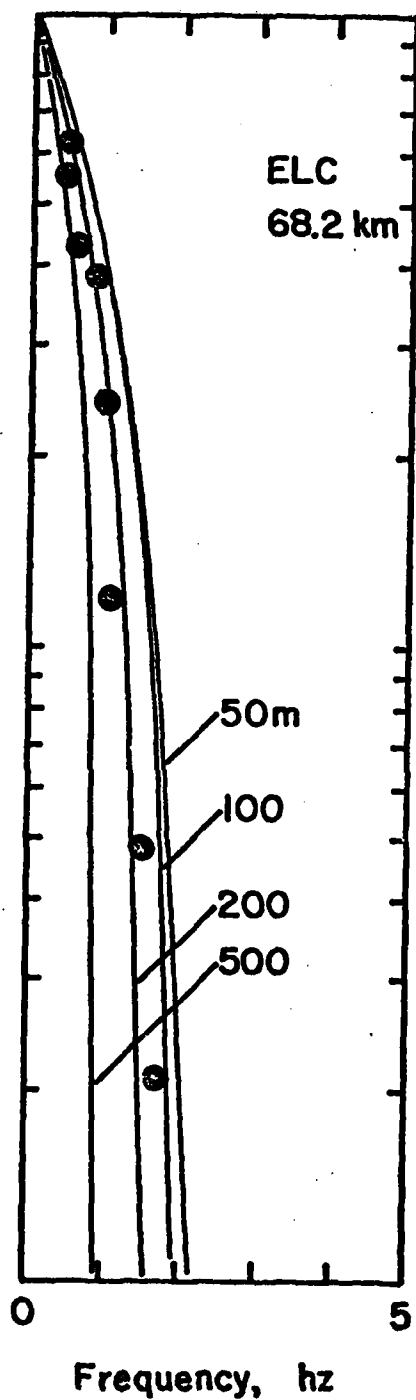
Figure 7. Comparison of observed amplitudes with theoretical amplitudes for various thicknesses of low-Q material. Q values for the low-Q and High-Q layers were taken to be 25 and 100, respectively. Thicknesses in meters appear by each curve.

as the source in this case. Figure 7 indicates that an
average thickness of the low Q material of about 200 meters
between the earthquake and station ELC best explains the
amplitude observations.

Reference

Tatham, R. H., Surface wave dispersion applied to the detection of sedimentary basins, Geophysics, 40, 40-55, 1975.